

How Apex Automates CPM-GOMS

Michael Freed	NASA / UWF
Michael Matessa	NASA
Roger Remington	NASA
Alonso Vera	NASA / CMU





CPM-GOMS has practical value

CPM-GOMS: an HCI technique for predicting average durations of brief, routine tasks. Perhaps the most successful predictive HCI technique.



Project Ernestine: application of CPM-GOMS saved Bell Atlantic millions of dollars per year



CPM-GOMS makes accurate predictions

The ATM Task

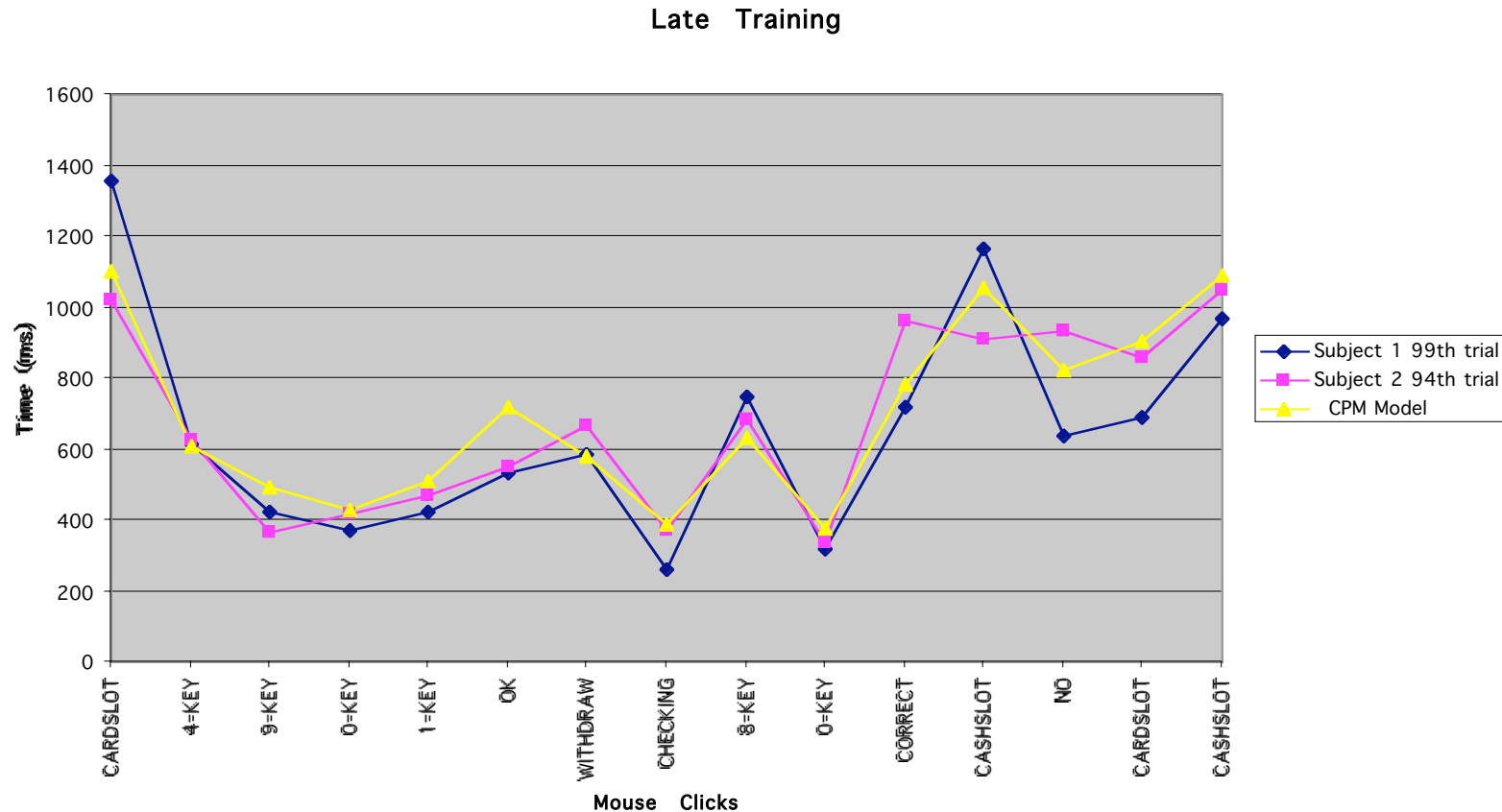


Steps:

- Insert card (click card slot)
- Enter PIN (4901)
- Press OK
- Select transaction type (withdraw)
- Select account (checking)
- Enter amount (80)
- Press if correct/not correct? (correct)
- Take cash (click cash slot)
- Other Transaction (no)
- Take card (click card slot)
- Take receipt (click cash slot)

CPM-GOMS makes accurate predictions

Well-Practiced Subjects vs. CPM-GOMS



**- Baskin & John, 1999
found similar results**

Talk outline

1. **Almost formal definition of GOMS & CPM-GOMS**
2. Creating Apex models that behave in accordance with CPM-GOMS (briefly)
3. Value of reproducing this capability in other architectures

GOMS

Goals, Operators, Methods, Selection rules

Top-level
Goal

Get 80€ from ATM

Start with a top-level goal representing the task of interest

GOMS

Goals, Operators, Methods, Selection rules

Top-level
Goal

Get 80€ from ATM

Method 1

- G: get ?amt from atm
1. init ATM session
 2. withdraw ?amt
 3. close session

Select a method appropriate for the specified goal

GOMS

Goals, Operators, Methods, Selection rules

Top-level
Goal

Get 80€ from ATM

Method 1

G: get ?amt from atm
1. init ATM session
2. withdraw ?amt
3. close session

Method 2

G: get ?amt from atm
1. init ATM session
2. deposit check
3. get ?amt cash back
4. close session

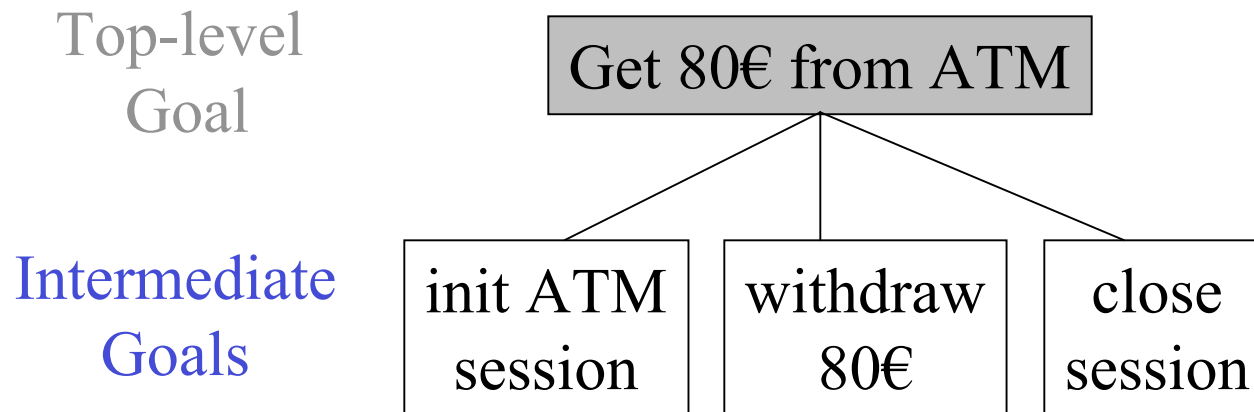
Selection Rule

if have-check
then Method 2
else Method 1

Use a selection rule if multiple methods apply

GOMS

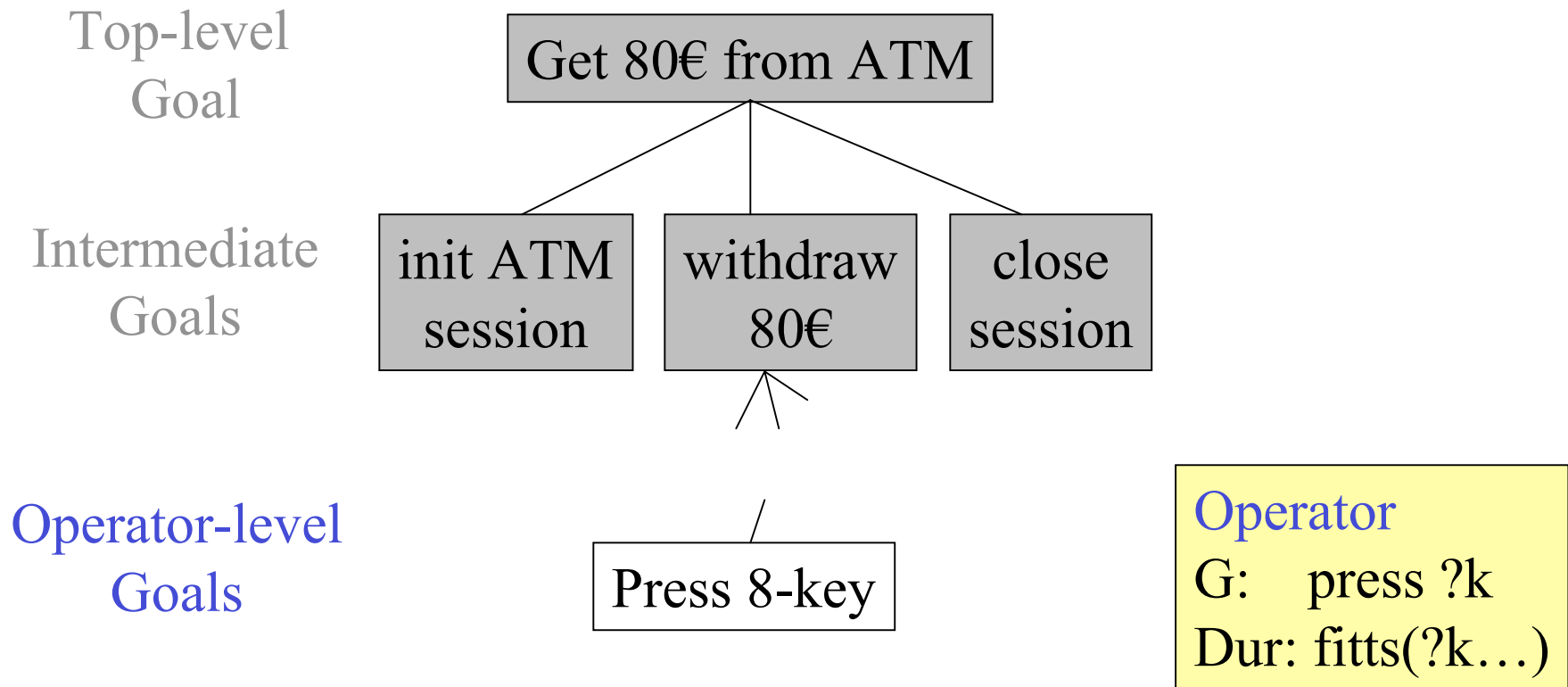
Goals, Operators, Methods, Selection rules



Decompose goal into subgoals, one for each step in method

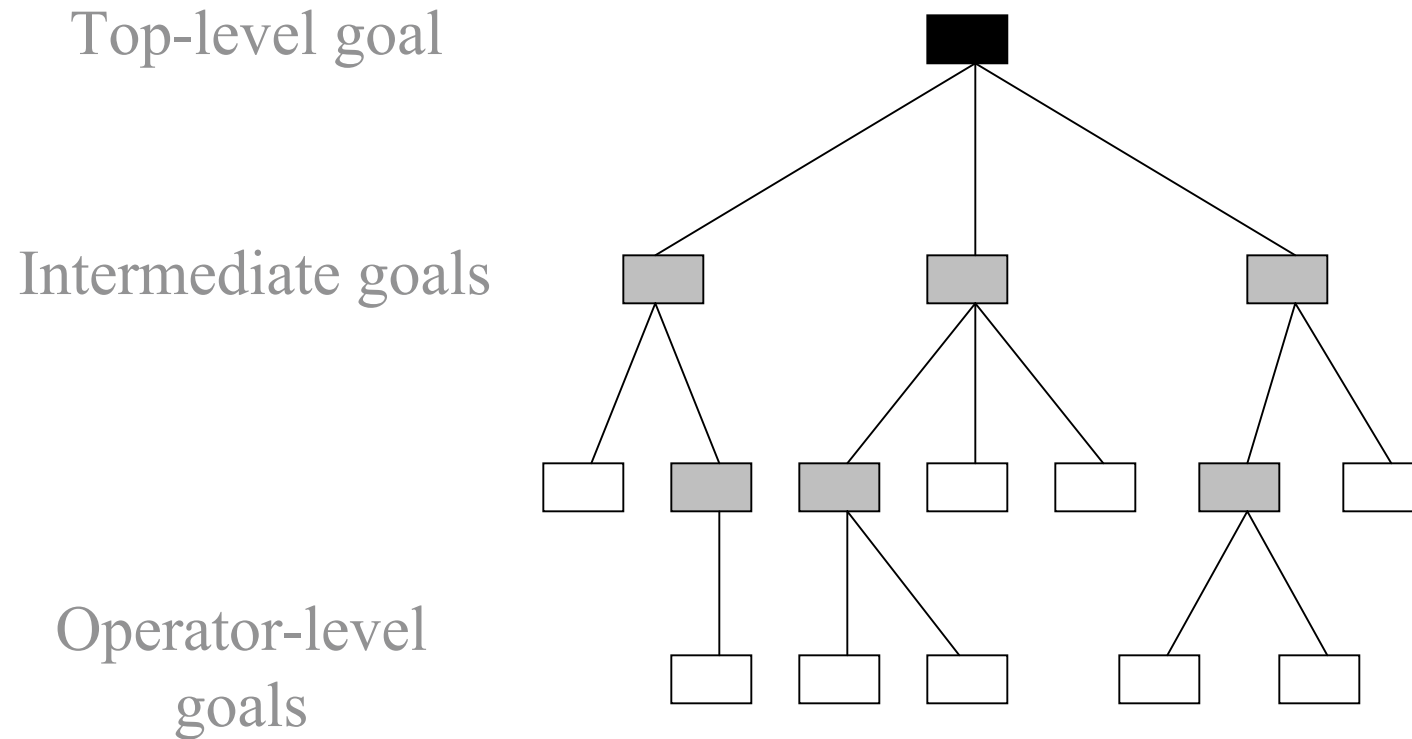
GOMS

Goals, Operators, Methods, Selection rules



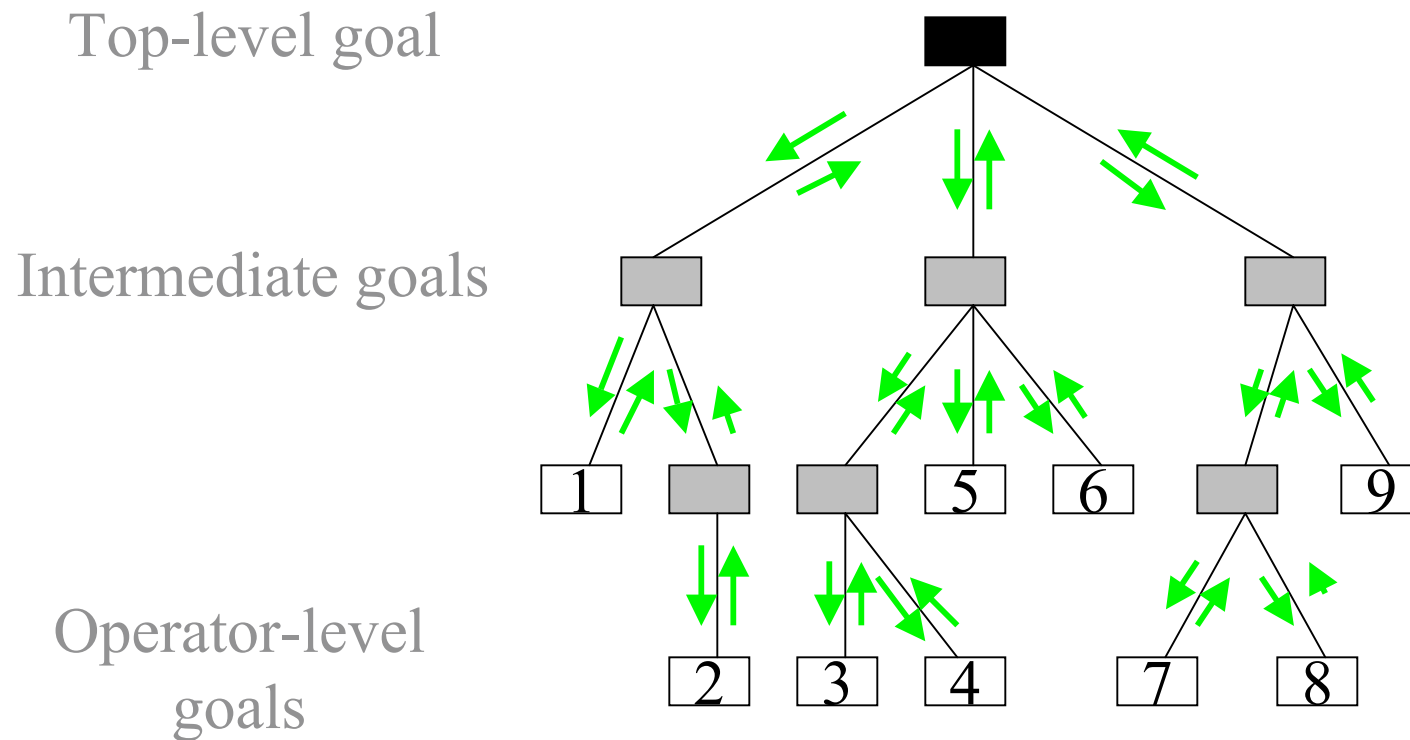
Don't decompose goals that match an operator definition

GOMS Goal Hierarchy



Predicted action sequence

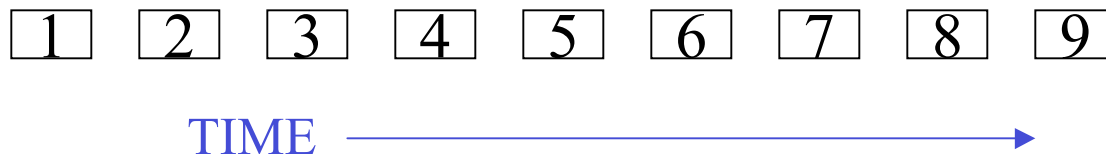
Depth-first Traversal



Predicted task duration

In GOMS, an operator-level goal and its associated operator definition specifies:

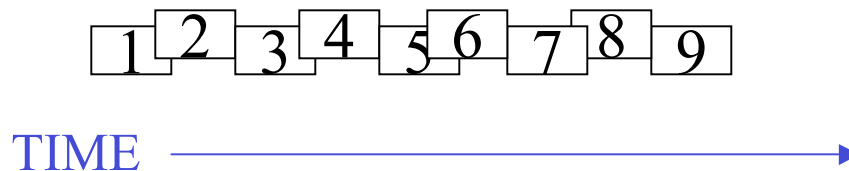
- an HCI action (e.g. mouse-to-target, press-button)
- a duration for the action



$$\text{Duration}(\text{task}) = \sum \text{Duration} (O_i)$$

Problem: execution overlap

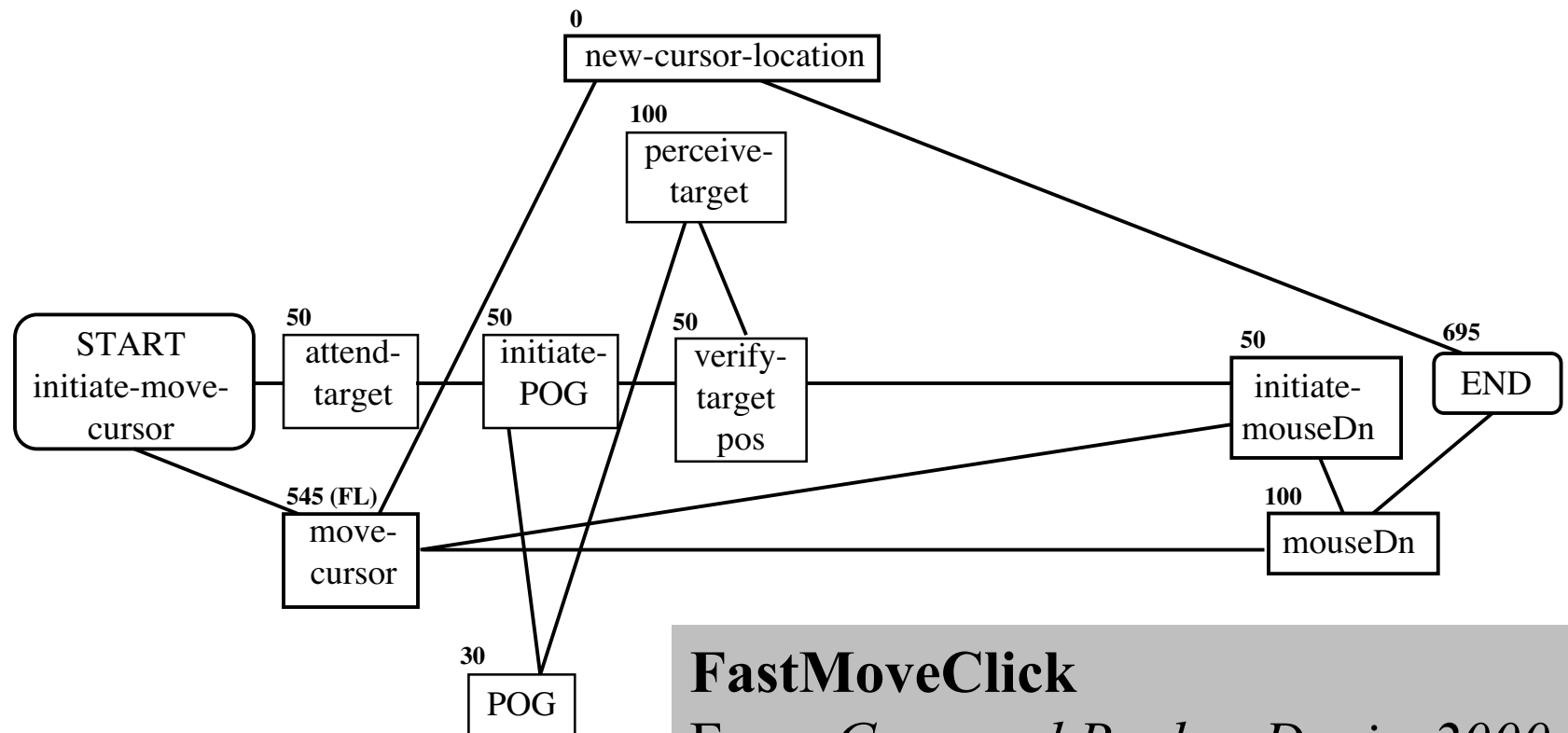
People carry out highly-practiced HCI-level actions with some degree of execution overlap (concurrency). GOMS' assumption of strict sequence reduces its value as an engineering technique.



CPM-GOMS differs from GOMS in that it accounts for overlap

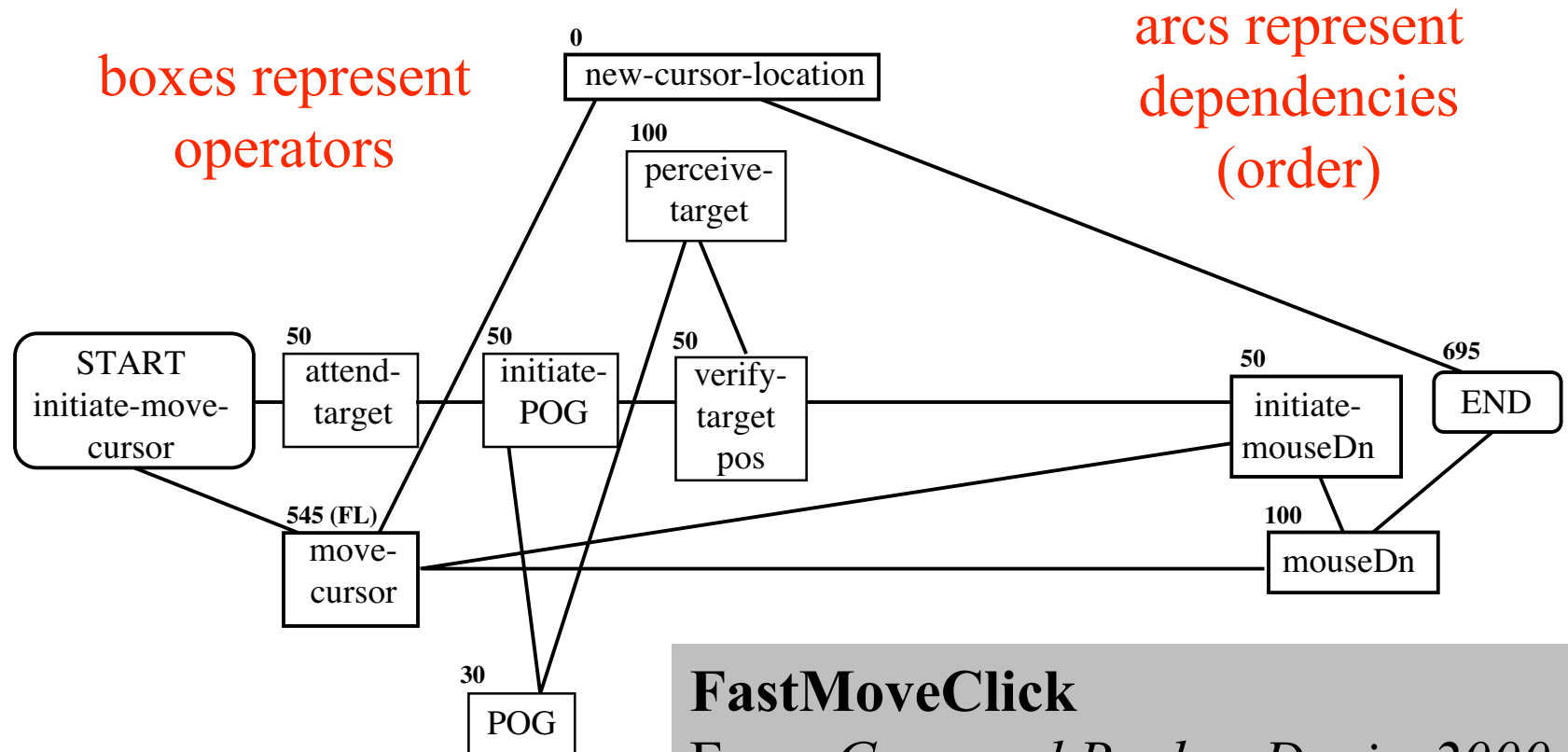
CPM-GOMS

Solution: model GOMS operators as “templates” consisting of partially-concurrent cognitive, perceptual and motor actions; ...



CPM-GOMS

Solution: model GOMS operators as “templates” consisting of partially-concurrent cognitive, perceptual and motor actions; ...



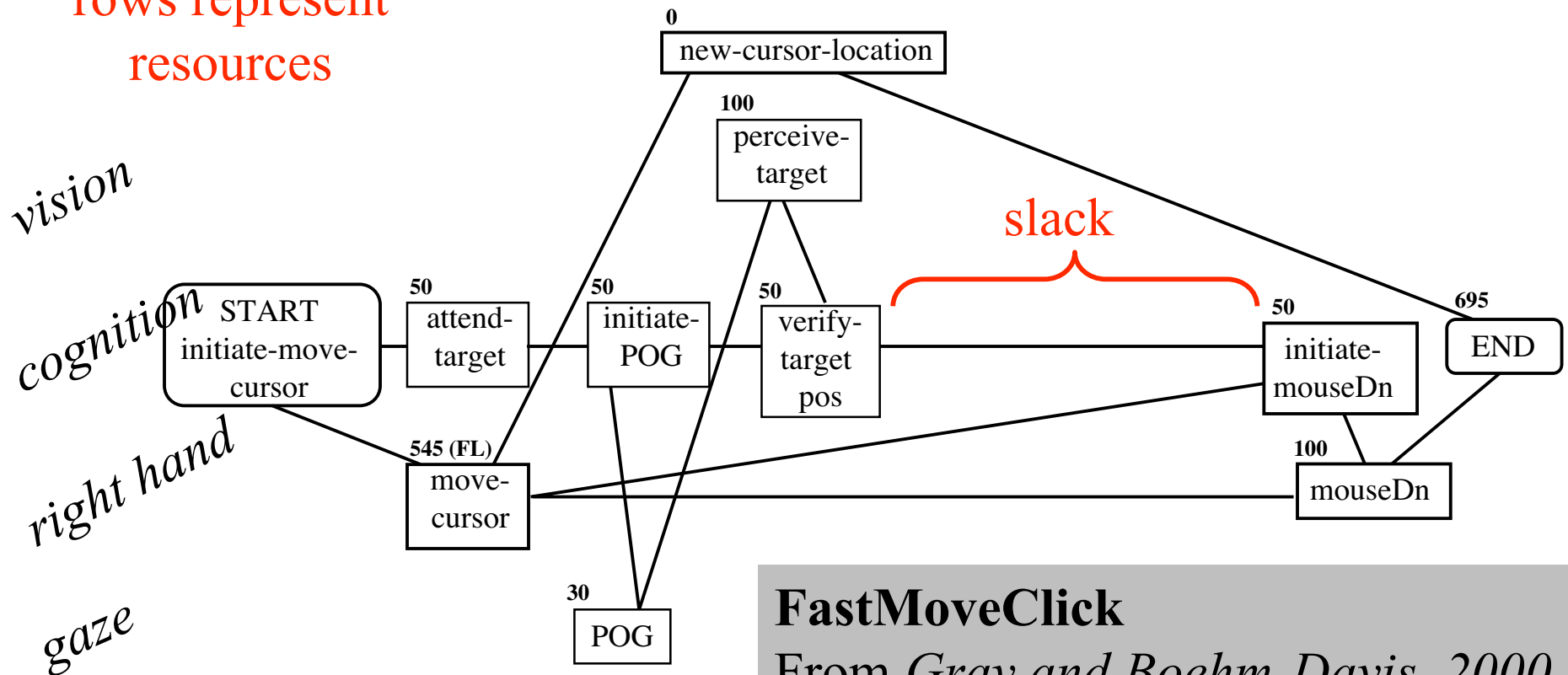
FastMoveClick

From *Gray and Boehm-Davis, 2000*

CPM-GOMS

Solution: model GOMS operators as “templates” consisting of partially-concurrent cognitive, perceptual and motor actions; ...

rows represent
resources

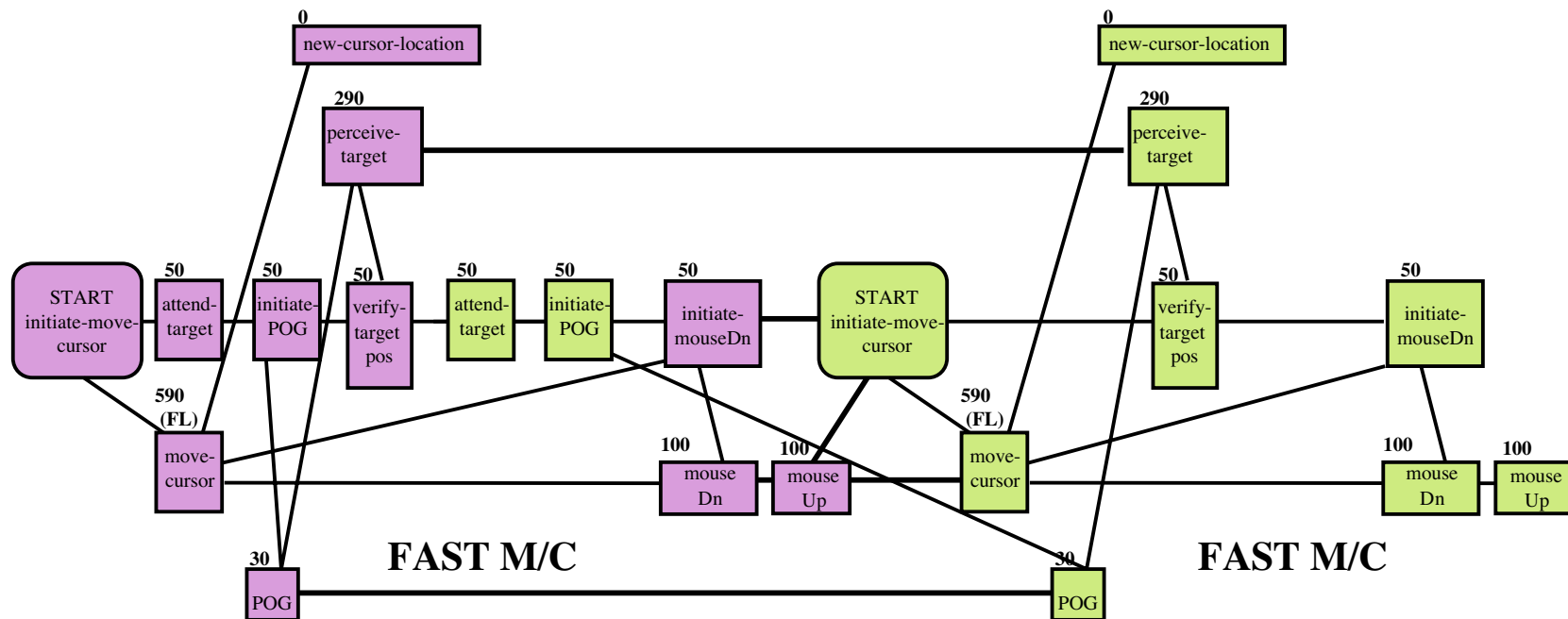


FastMoveClick

From *Gray and Boehm-Davis, 2000*

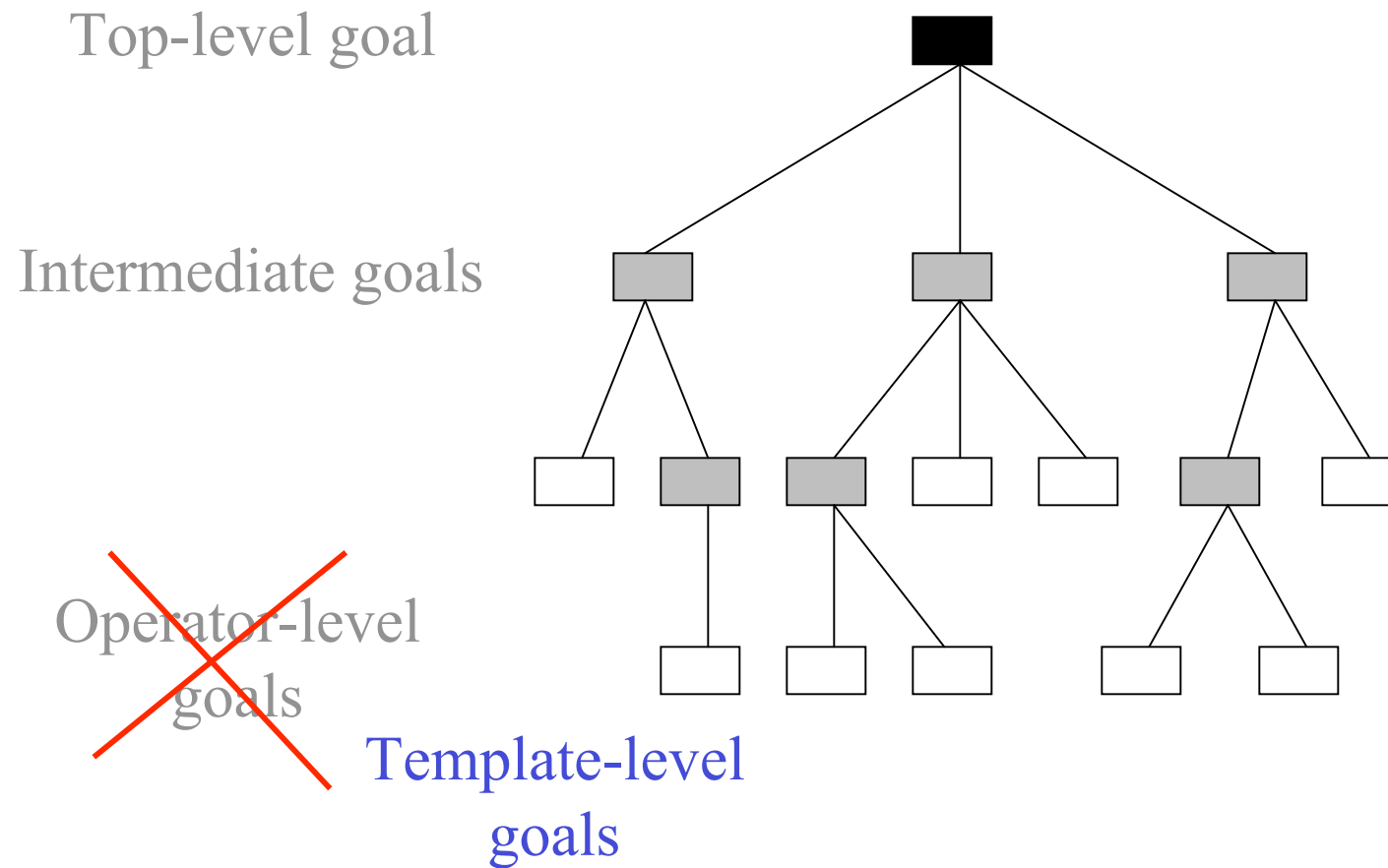
Dynamic task interleaving

Solution cont'd: ...then compute optimal interleaving of CPM-level actions to predict temporal overlap at the operator-level



total time for pair < sum for each individually

CPM-GOMS Goal Hierarchy



CPM-GOMS Goal Hierarchy

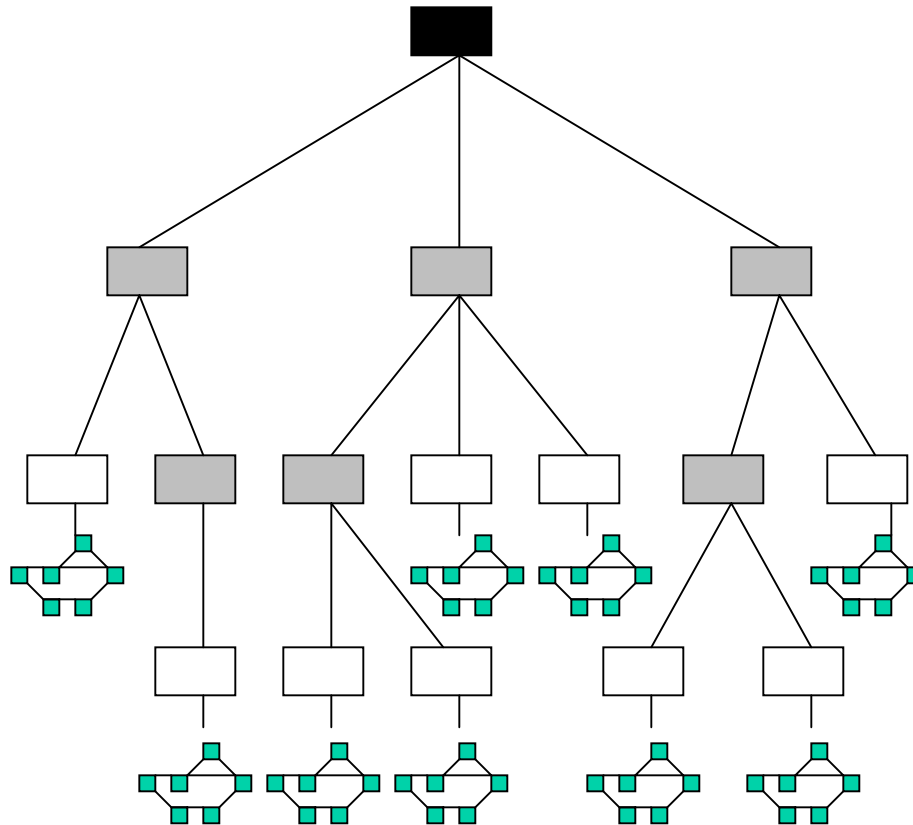
One level deeper

Top-level goal

Intermediate goals

Template-level
goals

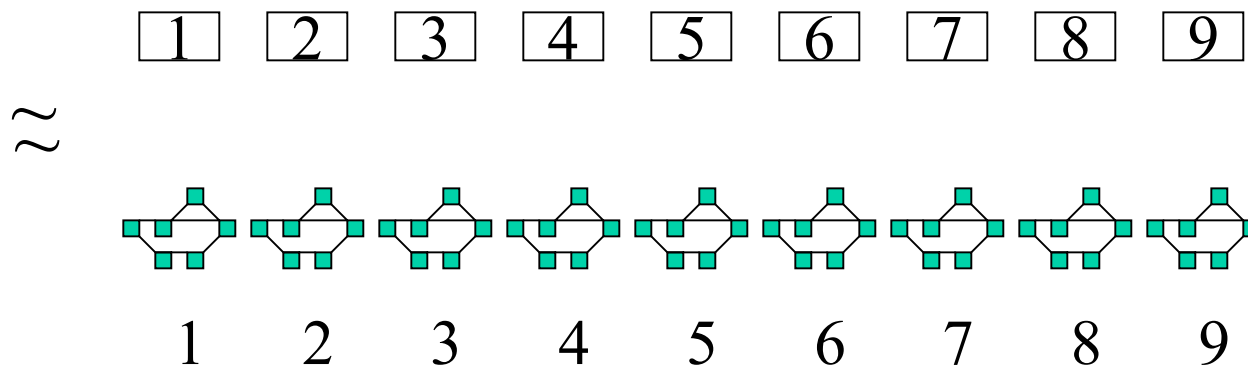
Operator-level
goal networks



Accounting for overlap

In GOMS, depth-first traversal ordered operator-level goals.

In CPM-GOMS, it orders template-level goals (operator networks)

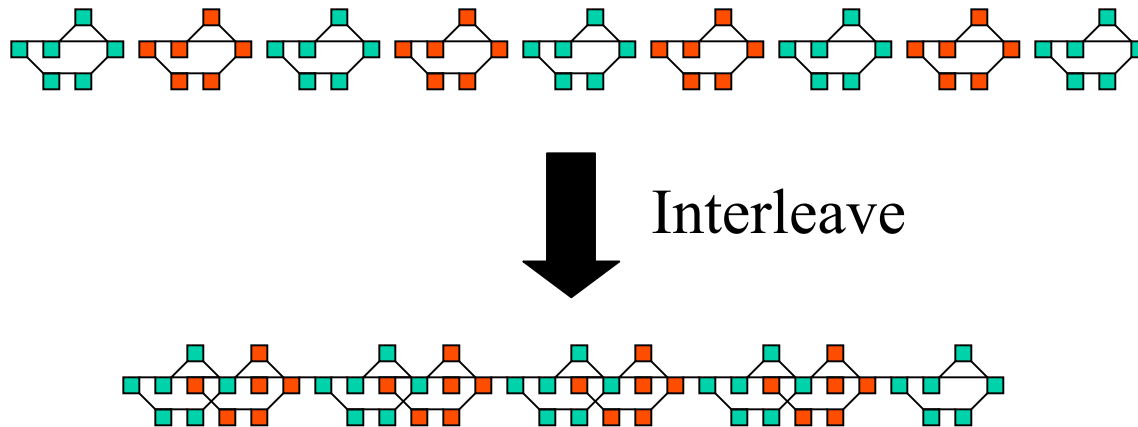


The meaning of the ordering is different in CPM-GOMS...

Accounting for overlap

In GOMS, order specifies strict execution sequence.

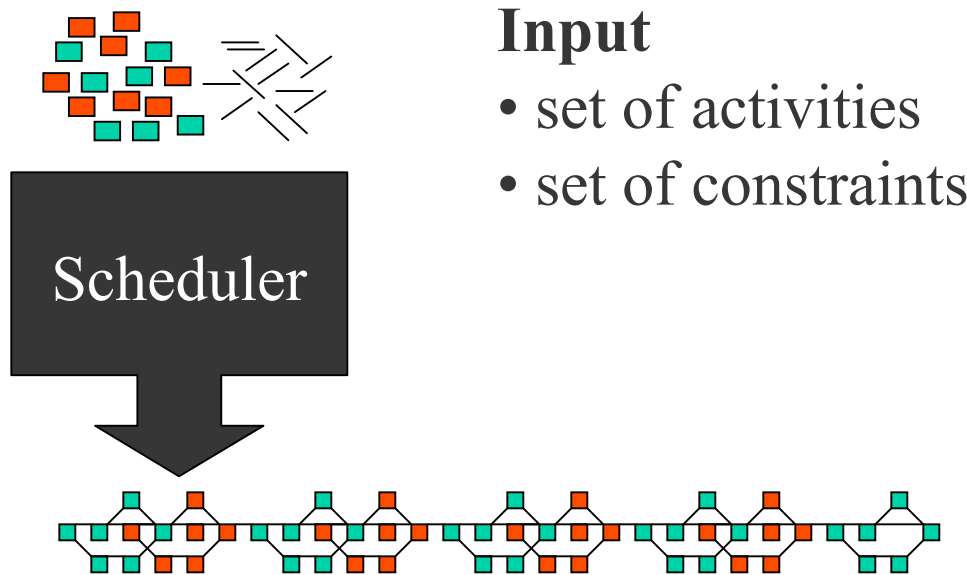
In CPM-GOMS, order defines *precedence* values that govern the interleaving of operators from different template-level goals.



Interleaving at the level of CPM-GOMS operators corresponds to overlapping execution at the level of HCI actions.

Accounting for overlap

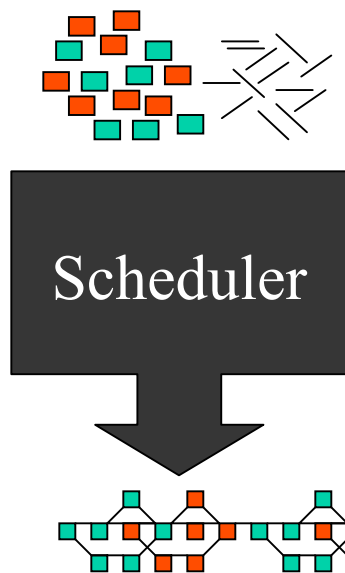
Correct interleaving can be formally described as a *constraint-based scheduling optimization problem*.



Output
shortest schedule that
includes all activities,
meets all constraints

Accounting for overlap

Correct interleaving can be formally described as a *constraint-based scheduling optimization problem*.

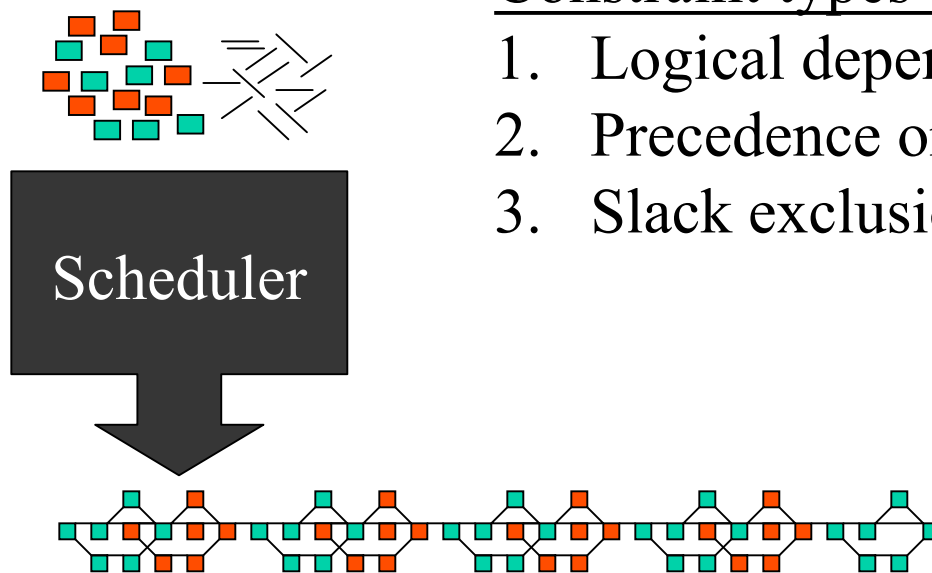


Example Activity

action: shift-gaze-to 5-key ← from hierarchy
precedence: 5 ← from DF traverse
duration: 250ms ← from operator definition
resource: gaze ← from operator definition

Accounting for overlap

Correct interleaving can be formally described as a *constraint-based scheduling optimization problem*.



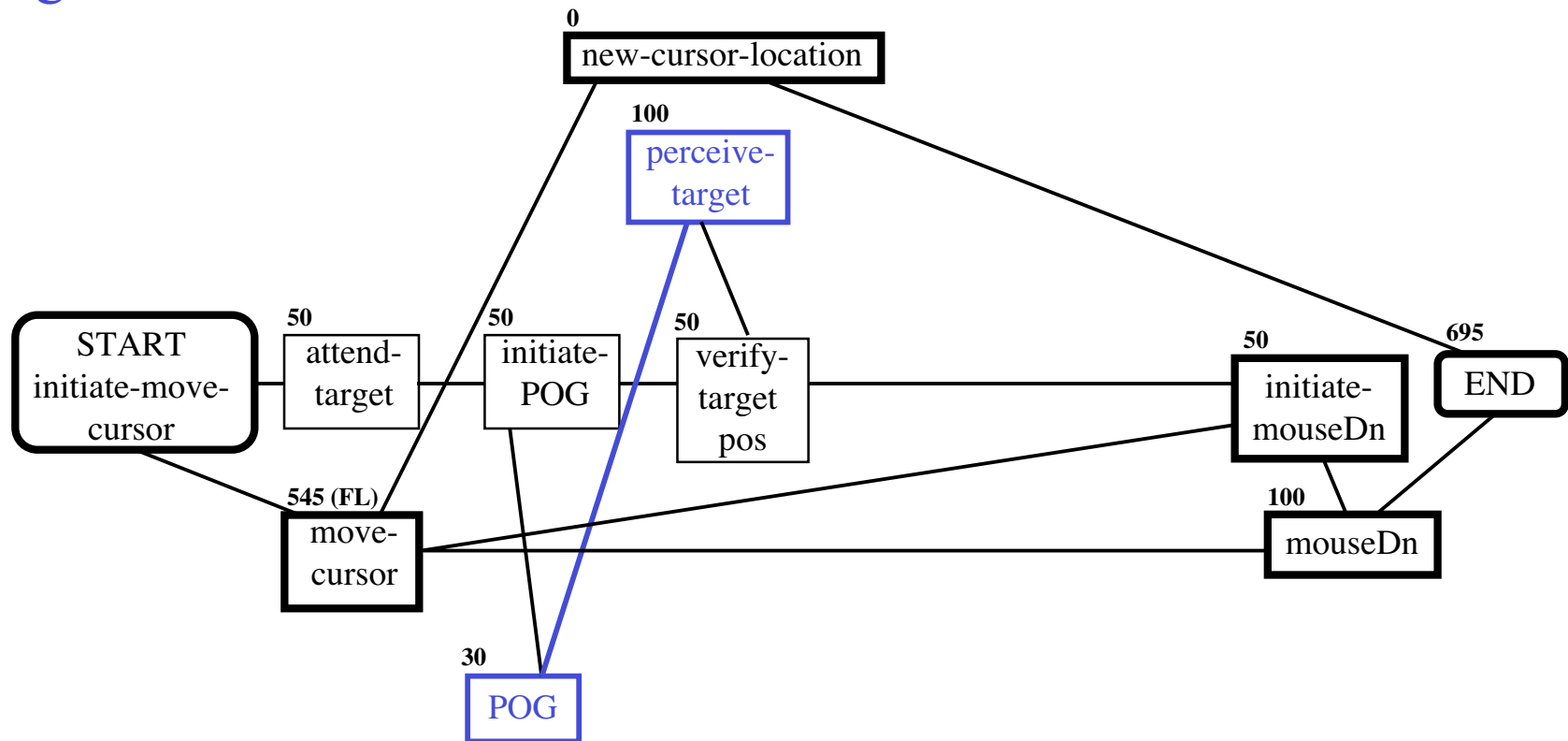
Constraint types used in CPM-GOMS

1. Logical dependencies
2. Precedence order
3. Slack exclusion

Logical Dependencies

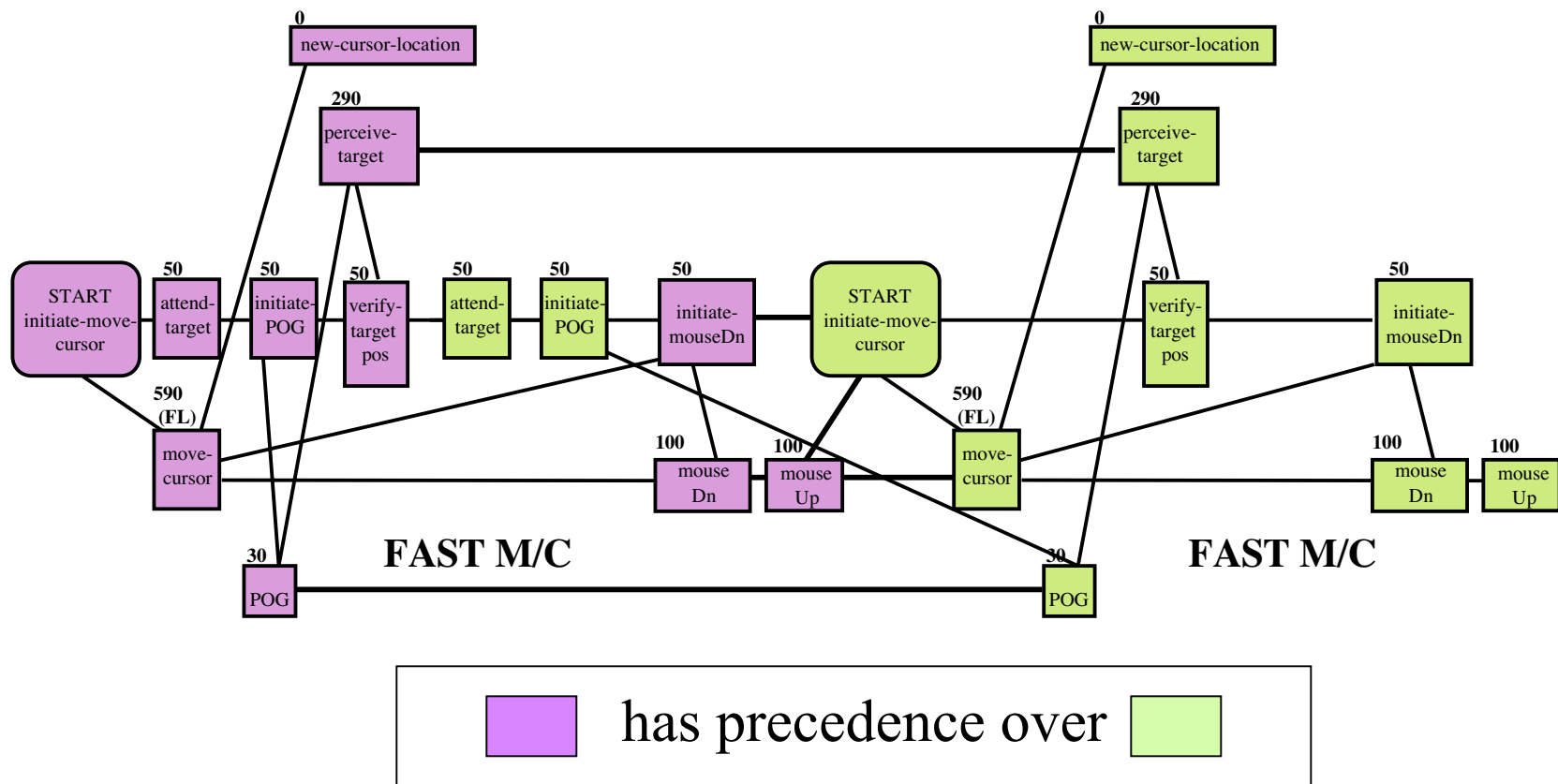
A satisfies a precondition for B so [A, B]

Example: gazing at target is a precondition for perceiving certain target attributes



Precedence Order Constraints

A and B need resource R, A has precedence so [A, B]

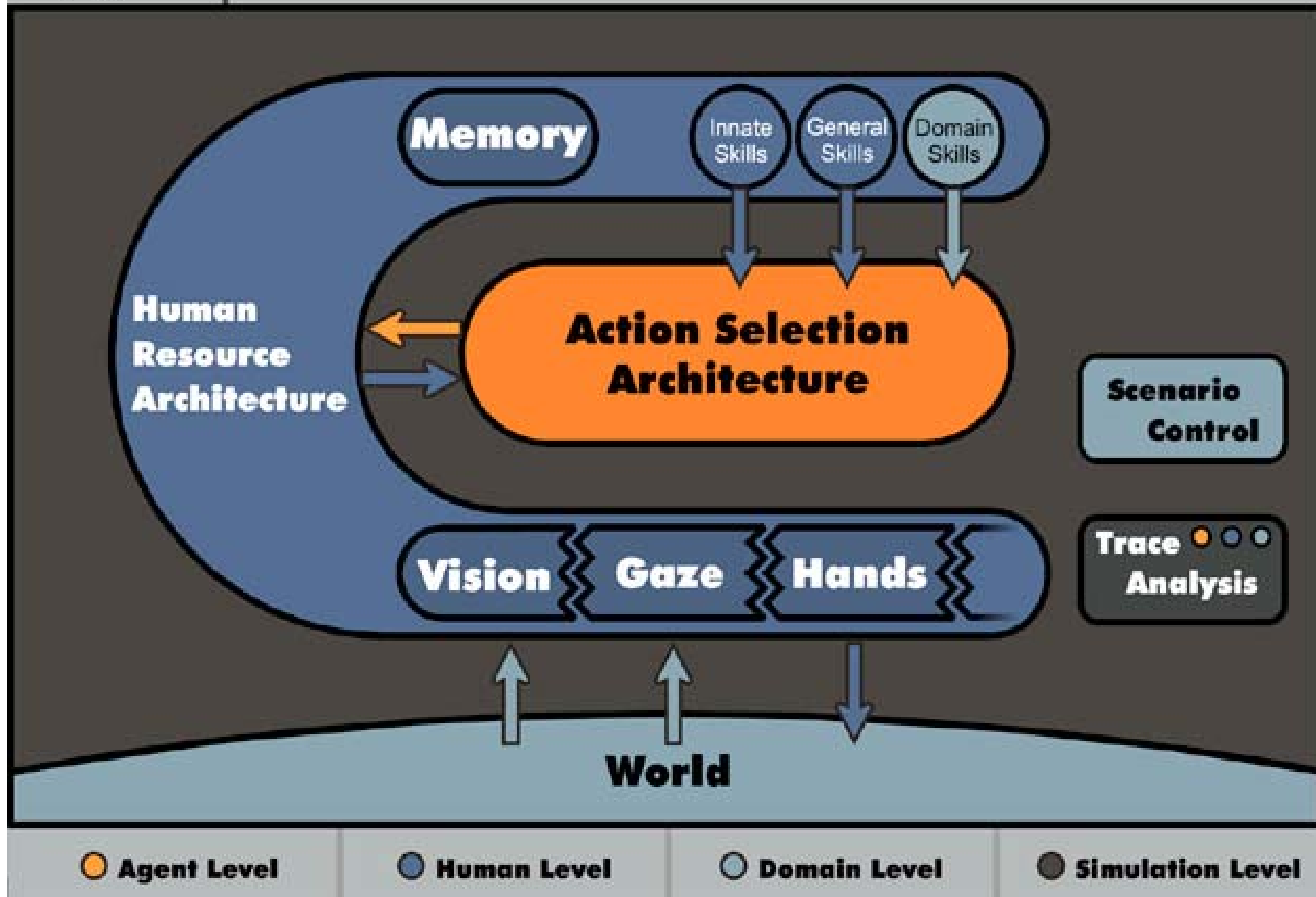


Slack exclusion constraints

G has subgoals A_1 and A_2 which define an interval that excludes any goal with property P ; B has P and lower precedence than A_i ; so $[A_2, B]$

Analogous example: when cooking a souffle', don't do any action that makes a lot of noise during a certain interval in the cooking process or the souffle' will collapse.

CPM-GOMS requires that otherwise available slack in the use of the cognition resource cannot be used to perform certain **cognitive-initiation** activities.



Behavior representation in Apex

- concurrency
- reactivity / cl-control
- hierarchy / selection
- contingency-handling
- multitask coordination

```
(procedure
  (index (delete-file ?file))
  (profile right-hand)
  (step s1 (find-and-grasp mouse))
  (step s2 (vis-locate ?file icon => ?icon))
  (step s3 (mouse-move to ?icon) (waitfor ?s1 ?s2))
  (step s4 (mouse-drag ?icon to trash) (waitfor ?s3))
  (step c1 (terminate) (waitfor ?s4))
  (step c2 (restart ?self) (waitfor (interrupted ?self))))
```

Representing Methods

(procedure

(index (withdraw ?amount))

(step s1 (fast-move-click withdraw-button) (rank 1))

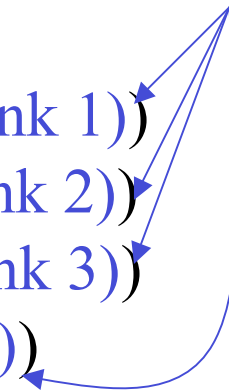
(step s2 (fast-move-click checking-button) (rank 2))

(step s3 (enter-number-sequence ?amount) (rank 3))

(step s4 (slow-move-click money-slot) (rank 4))

(step s5 (terminate) (waitfor ?s1 ?s2 ?s3 ?s4)))

resource precedence
(precedence value)



Representing Templates

(procedure

(index (fast-move-click ?target))

(step c1 (initiate-move-cursor ?target))

(step h1 (**hold-resource RHB**) (waitfor ?c1))

(step m1 (move-cursor ?target) (waitfor ?c1))

(step c2 (attend ?target))

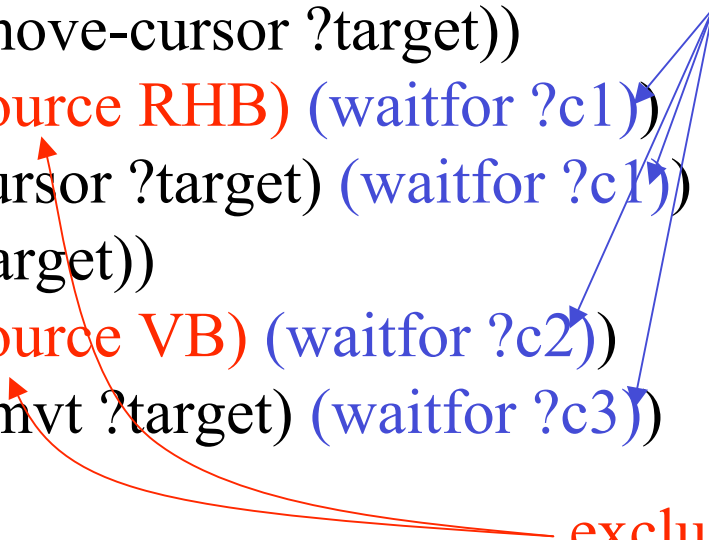
(step h2 (**hold-resource VB**) (waitfor ?c2))

(step c3 (init-eye-mvt ?target) (waitfor ?c3))

...)

logical dependencies

exclusion constraints
(temporal scope)



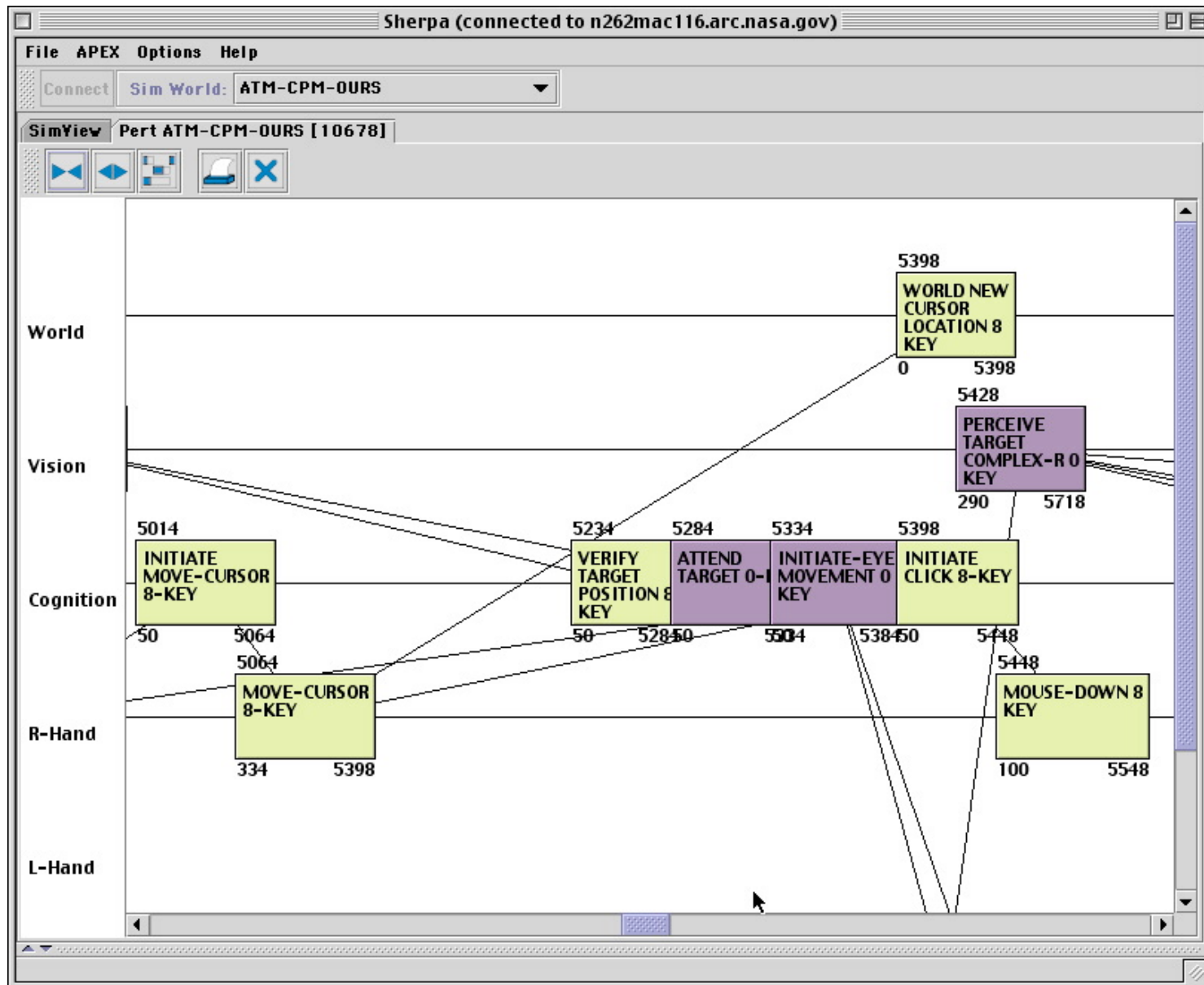
Representing Operators

exclusion constraint
(property assertion)

precedence constraint
(resource usage)

```
(procedure  
  (index (mouse-up))  
  (profile right-hand)  
  (step s1 (start-activity right-hand release-mouse-button  
             :object mouse :duration 100 => ?a)  
  (step s2 (terminate) (waitfor (completed ?a)))  
  (step c1 (reset ?self) (waitfor (resumed ?self))))
```

Apex-generated PERT chart for CPM-GOMS analysis



Implementing CPM-GOMS

Computer science concepts such as *depth-first traversal* and *constraint-based scheduling* are useful for formally defining a **correct** CPM-GOMS analysis.

CPM-GOMS in Apex

- implements formal definition of CPM-GOMS...
- but does not incorporate either of these algorithms; doing so would violate architectural commitment to reactive execution
- achieves required functionality indirectly -- example:

Instead of depth-first traversal which would give absolute precedence values, relative precedence inferred from rank giving relative values for local scheduling decisions.

CPM-GOMS in other architectures

Advantages for CPM-GOMS

- different architectural commitments would lead to different approaches and better understanding of HCI behavior
- different architectural strengths could result in diverse extensions to approach

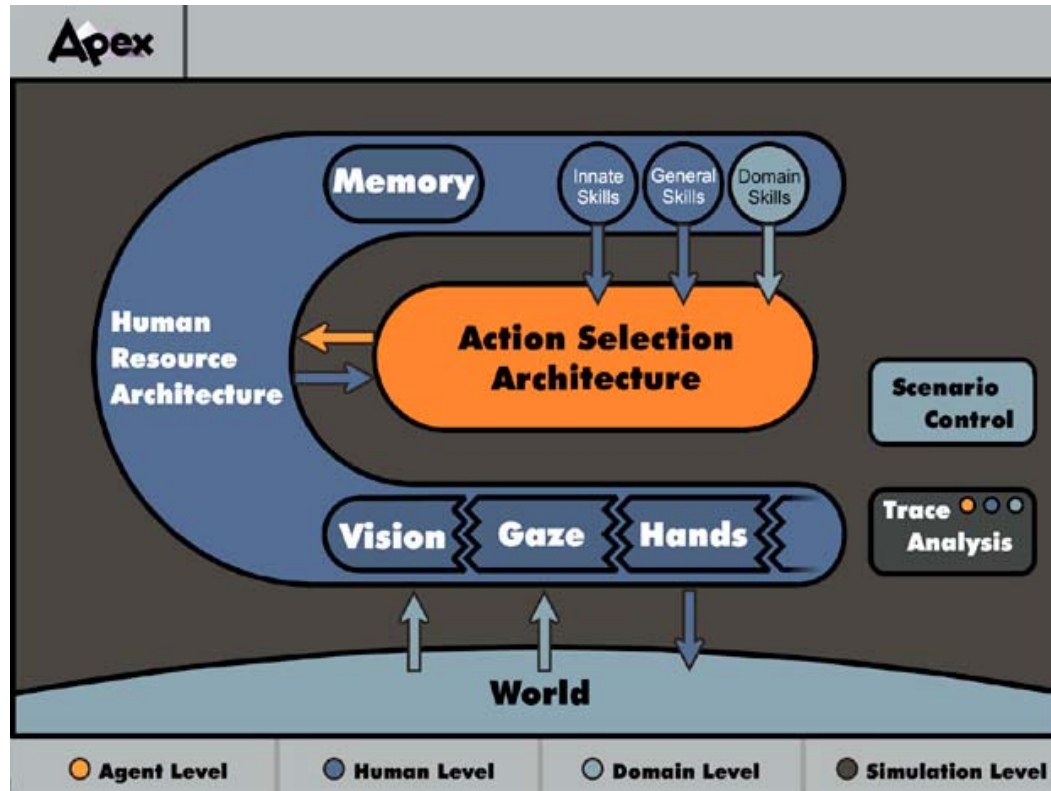
Advantages for cognitive modeling

- common problem may promote better understanding of strengths/weaknesses of individual architectures
- ...and may promote better differentiation of the deep vs. superficial differences between architectures

Download Apex 2.3

<http://human-factors.arc.nasa.gov/apex>

Apex Modeling Tool



Apex System

- Apex architecture (autonomy)
- Human resource architecture
- Reusable procedure lib
- World model widget libs
- Simulation "engine"
- GUI-based vis/debug tools
- GUI-based world dev tool
- Interoperability framework
- Manuals, tutorials, ...

Download system from: <http://human-factors.arc.nasa.gov/apex/>

User Support: apex-help@eos.arc.nasa.gov